GLAST Large Area Telescope
Calorimeter Subsystem

3.0 Systems Engineering

Bob Kraeuter
Naval Research Lab, Washington DC
Calorimeter Systems Engineer

rkraeuter@swales.com
(202)–404–1461

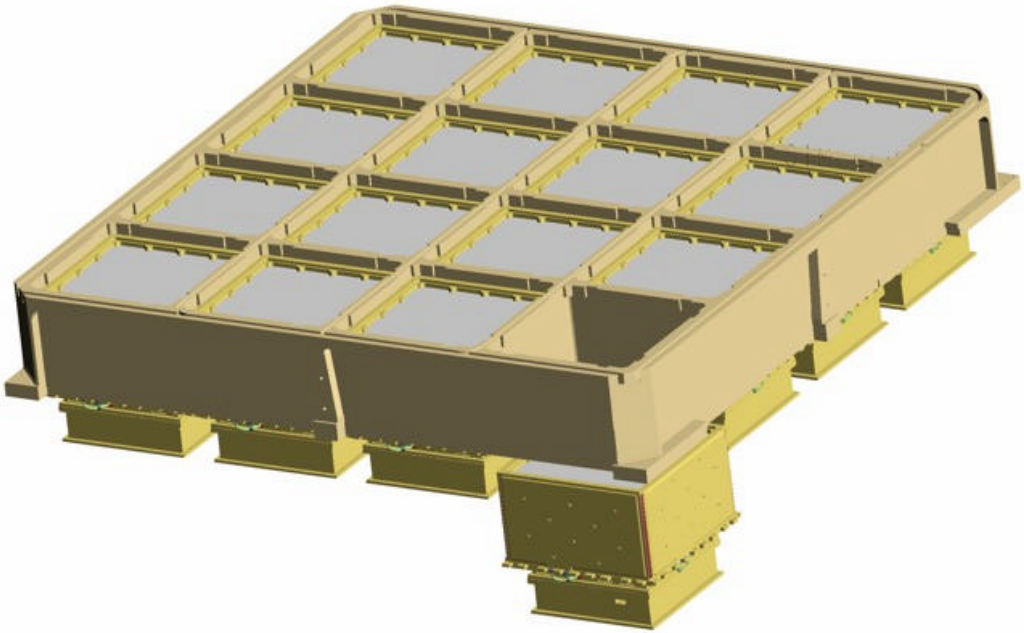
Outline

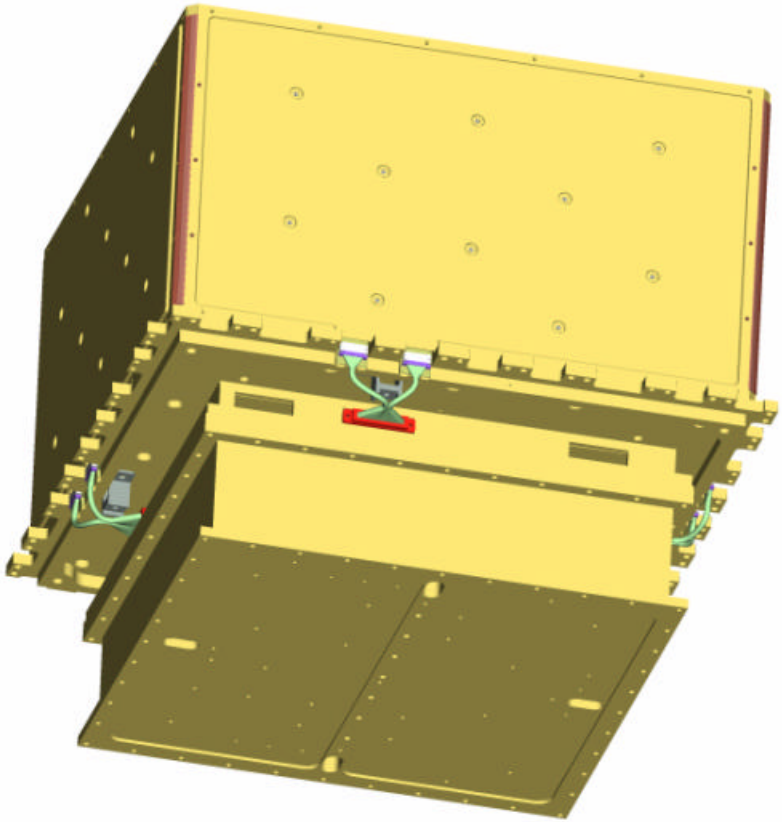
- System Overview
- Requirements
- Documentation Status
- Interfaces
- Technical Budgets
- Verification & Test
- Engineering Model

System Overview

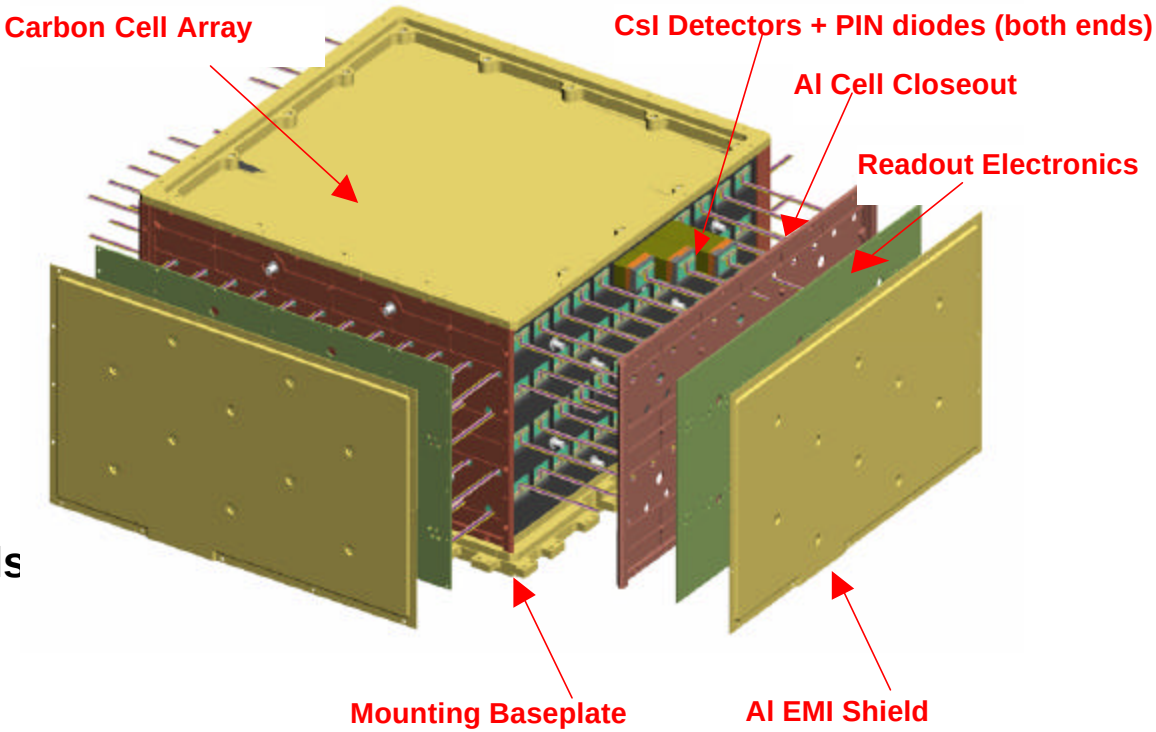
Modular Design

4 x 4 array of Calorimeter modules





System Overview

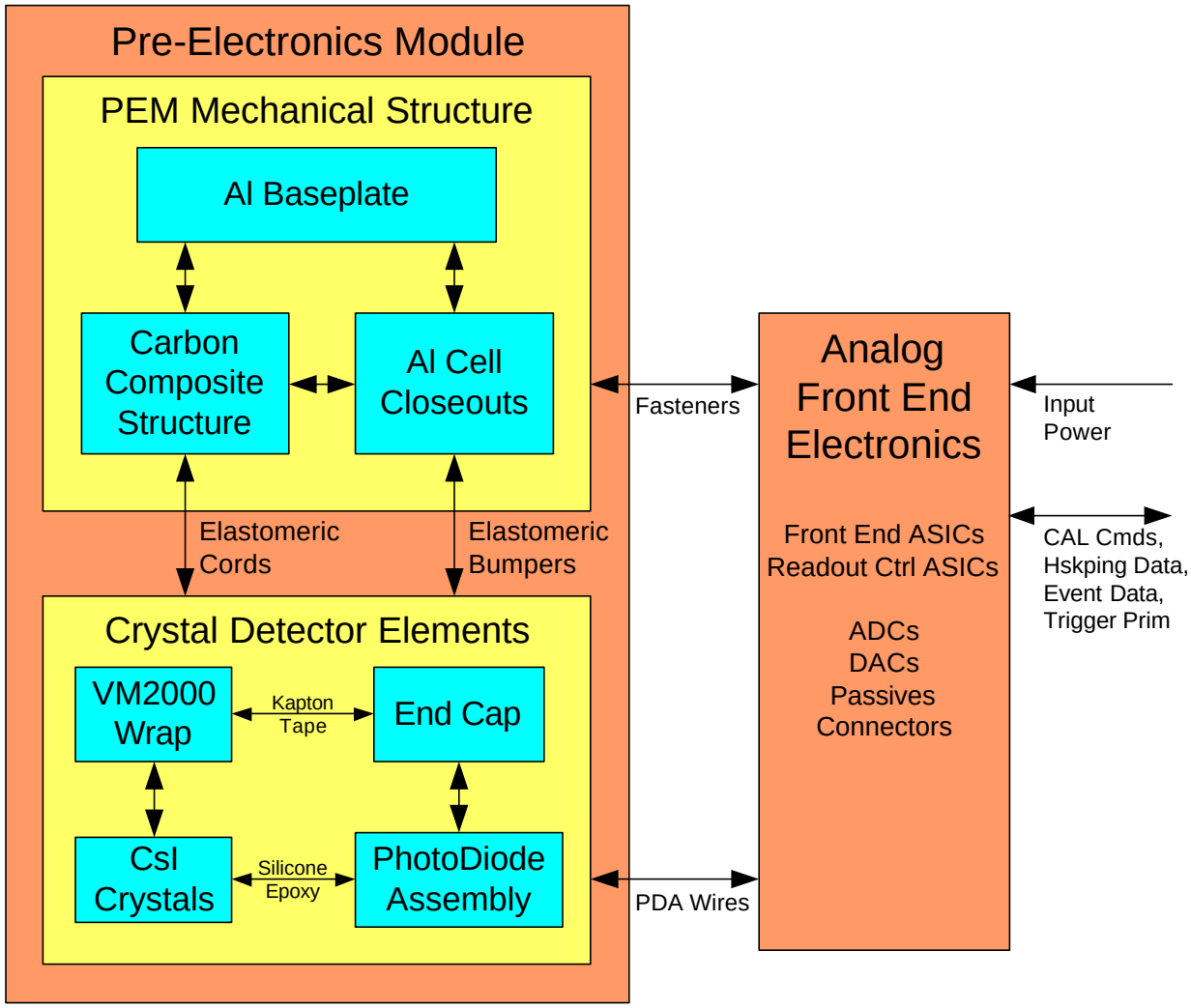


Each module

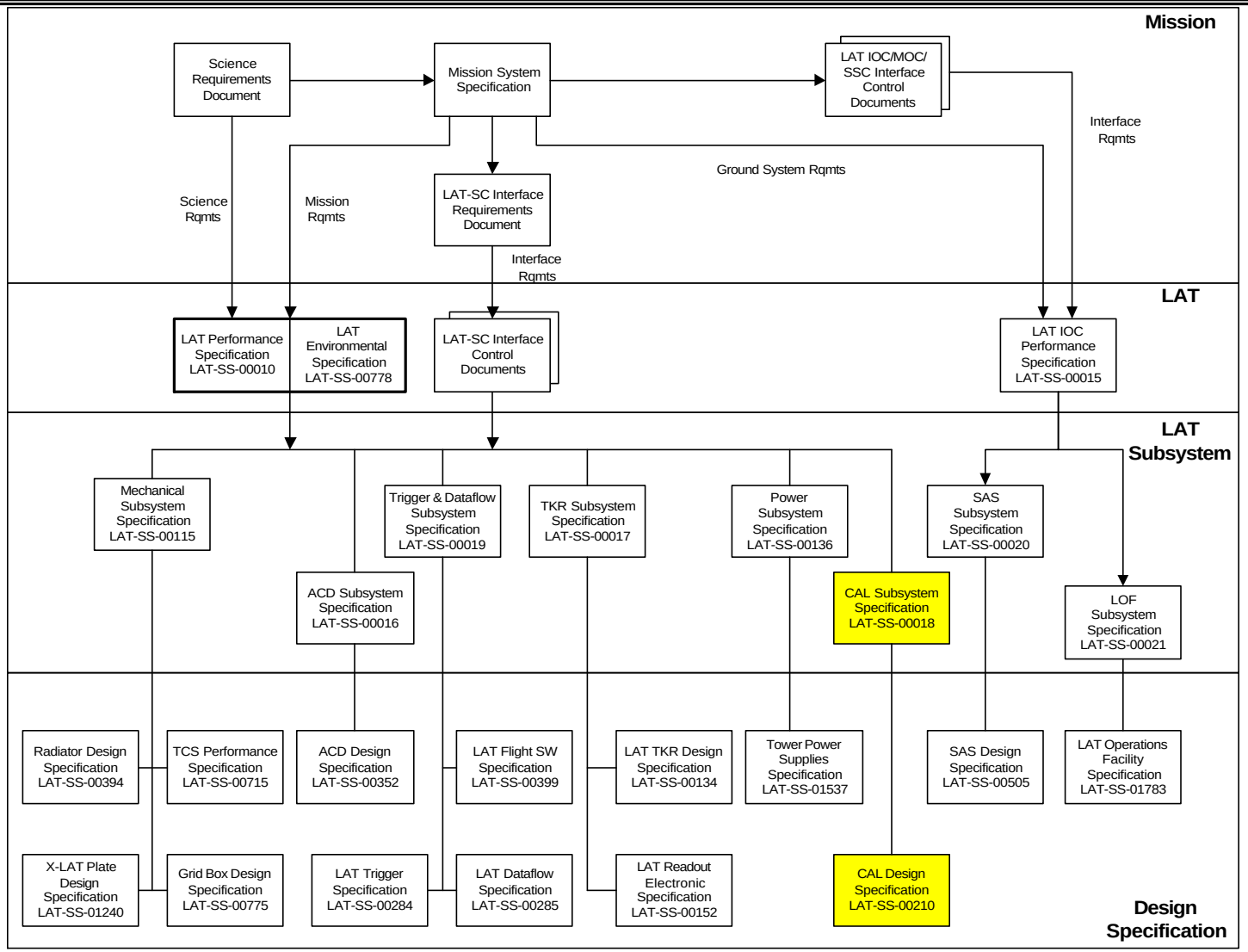
- 8 layers of 12 CsI(Tl) crystals
  - Crystal dimensions
    - 27 x 20 x 326 mm
  - Hodoscopic stacking
    - alternating orthogonal layers
- Dual PIN photodiode on each end of crystals
- Mechanical packaging
  - Carbon Composite cell structure

- Electronics boards attached to each side
  - Interface connectors at base of calorimeter
- Outer wall is EMI shield and provides structural stiffness as well

Calorimeter Module Architecture



Requirements Flow



CAL Level III Requirements

Reference: LAT-SS-00018

Parameter	Requirement	Verification	Expected Performance
Energy Range	20 MeV – 300 GeV 20 MeV – 1 TeV (goal) 5 MeV – 100 GeV, single crystal	Simulation, Beam Tests	Required performance ~2 MeV threshold (BOM)
Energy Resolution (1 sigma)	< 20% (20 MeV < E < 100 MeV) < 10% (100 MeV < E < 10 GeV) < 6% (10 GeV < E < 300 GeV, incidence angle > 60 deg)	Simulations and EM and LAT calib unit Beam Tests	Simulations demonstrate required performance
Energy Resolution (1 sig) Single Crystal	< 2% for Carbon Ions of energy >100 MeV/nuc at a point.	EM (and Calib Unit) beam test	< 0.5% (correlation of ends removes Landau)
Design	Modular, hodoscopic, CsI > 8.4 RL of CsI on axis	Inspection	8.6 RL
Active Area	>1050 cm^2 per module < 16% of total mass is passive mtrl.	Inspection	1080 cm^2 per module < 14% is passive
Position Resolution	< 3 cm in 3 dims, min ionizing particles, incident angle < 45 deg.	Test with cosmic muons, all modules	< 1.5 cm in longitudinal measurement
Angular Resolution	15 ´ cos(q) deg, for cosmic muons in 8 layers	Test with cosmic muons, all modules	8 ´ cos(q) deg
Dead Time	< 100 ms per event < 20 ms per event (goal)	Test	< 22 ms per event

CAL Level III Requirements (cont)

Parameter	Requirement	Verification	Expected Performance
Low Energy Trigger	>90% efficiency for 1 GeV photons traversing 6 RL of CsI < 2 μs trigger latency	Simulations	> 93% < 1 μs
High Energy Trigger	>90% efficiency for 20 GeV photons depositing at least 10 GeV < 2 μs trigger latency	Simulations, Calib unit test in beams	> 91% < 1 μs
Size (module)	< 364 mm in width (stay clear) < 224.3 mm in height (stay clear)	Inspection	363 mm 224 mm
Mass	< 1440 kg (90.0 kg/module)	Test	1376 kg
Power	< 91 Watts (conditioned) ** (5.69 W/module)	Test	< 54 Watts (conditioned)
Temperature Range	– 10 to +25 C, operational – 20 to +40 C, storage – 30 to +50 C, qualification	Subsystem TV Test 4 cycles, acceptance 12 cycles, qualification	Required performance
Reliability	> 96% in five years	Analysis	> 98% in five years (15/16 modules) LAT-TD-00464-03

*** Modified to 64 Watts, pending CCB action***

Derived Requirements

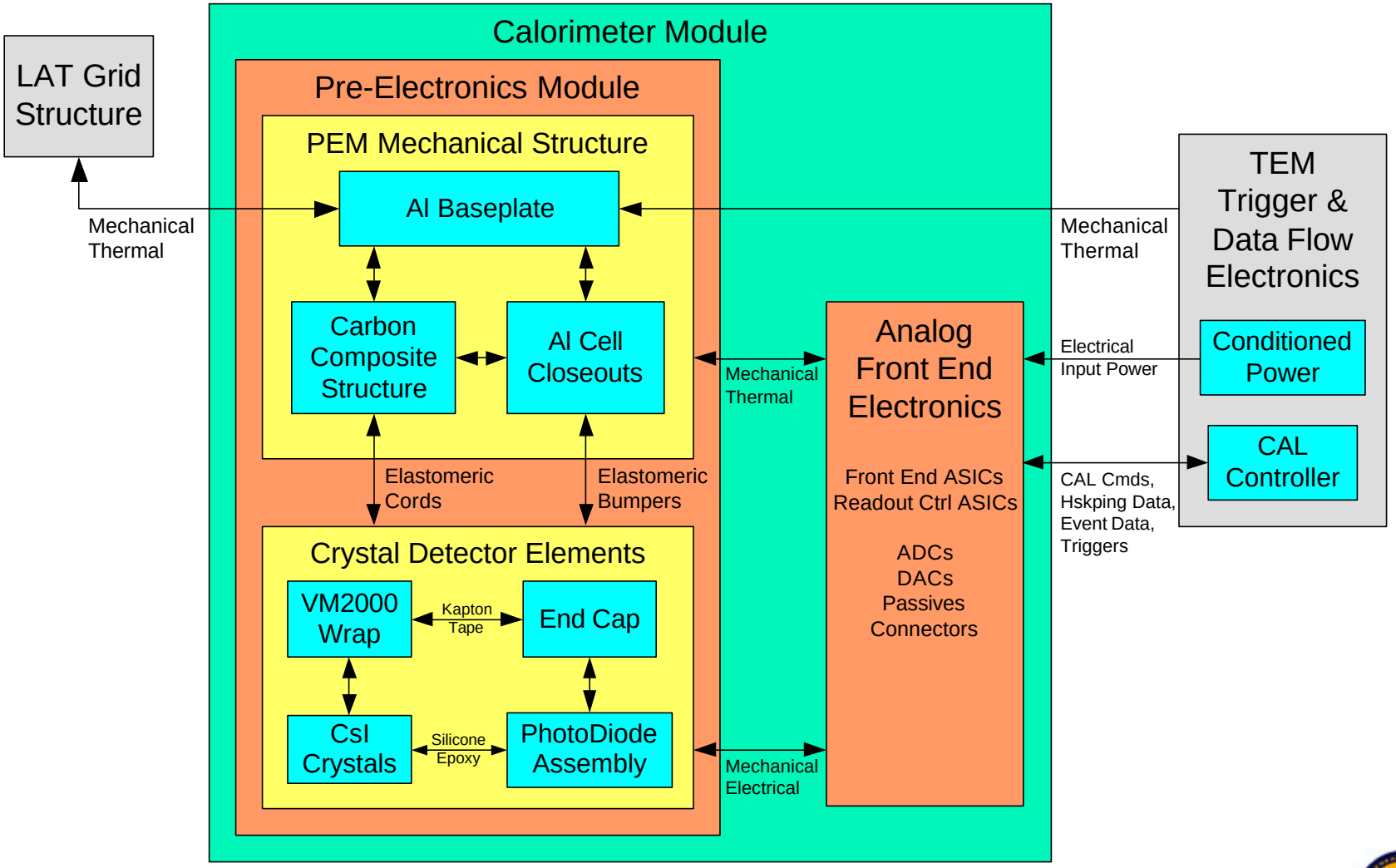
- **LAT CAL Subsystem Level IV Specification – LAT-SS-00210**
  - **Contains 164 detailed design requirements derived from CAL Level III Specification – LAT-SS-00018**
- **LAT CAL Verification & Environmental Test Plan – LAT-SS-01345**
  - **Details approach to verifying each Level IV requirement**
    - **Lists verification methods used**
      - **Mostly verified by Test, 53 reqmts verified by analysis/inspection**
    - **Assembly levels at which verification is performed**
      - **114 requirements are verified at the components level**

Documentation Status

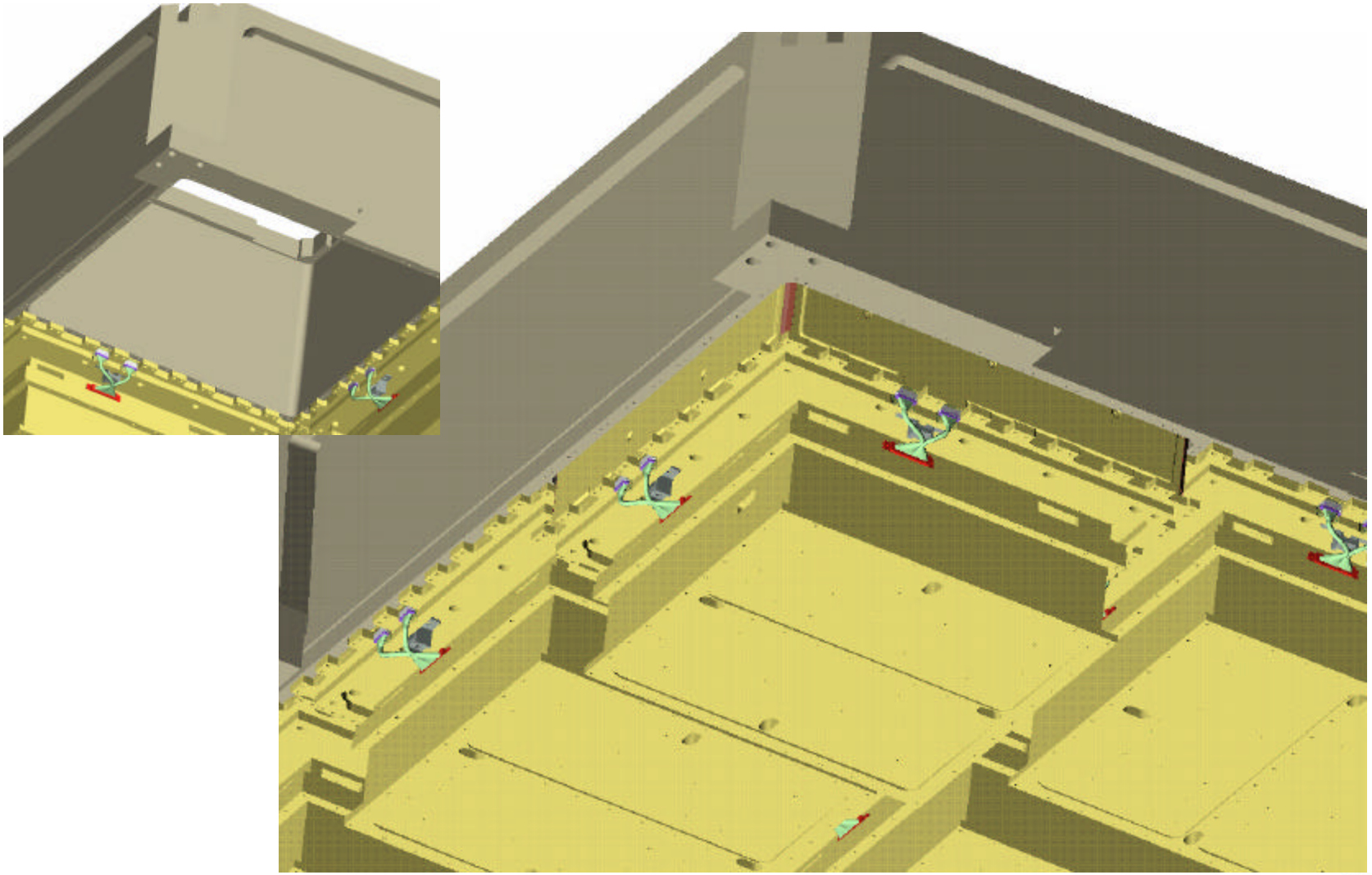
- **Major documents released**
  - CAL Subsystem Level III & IV specs
  - CAL – LAT Interface Control Document
  - CAL – LAT Interface Definition Drawing (needs update)
  - CAL Subsystem Verification & Environmental Test Plan

	Qty	Completion Date
Released Documents/Drawings	99	60% completed
Documents Near Completion	24	90% by March 29
Drafts	23	70% by April 19
Miscellaneous Procedures	7	100% by April 19
Flight ASIC Documentation	10	100% by May 10
AFEE Board Analyses	3	100% by May 10
Total	166	

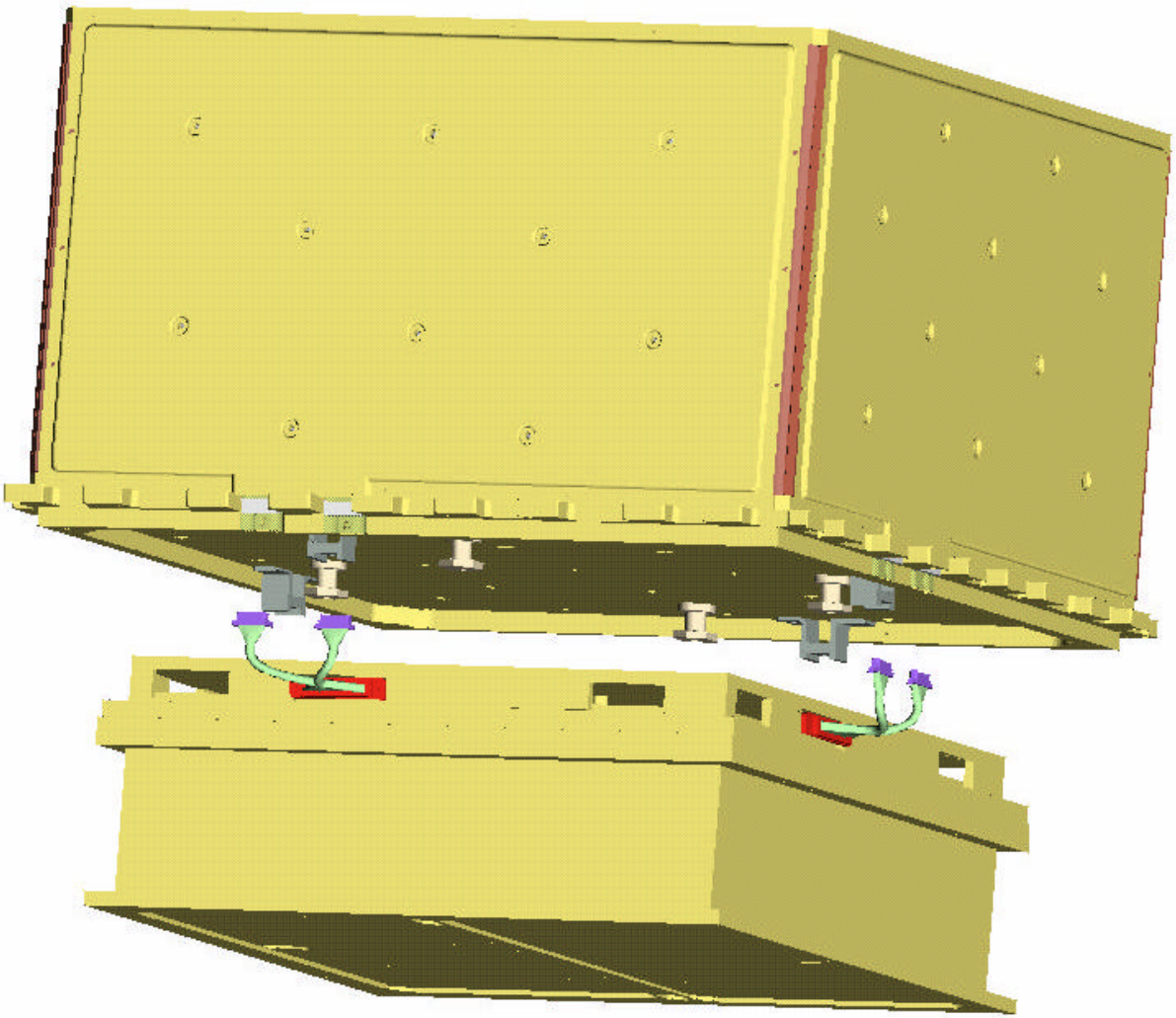
Calorimeter Interfaces



Mechanical Interface – CAL to Grid



Mechanical Interface – TEM to CAL



Mass Budget

The Calorimeter Subsystem meets LAT rqmts with a margin of 4.6%

Component	Material	Mass (kg)
Crystal Detector Elements	CsI Crystals	74.24
	Diodes, wire, wrapping	0.800
Composite structure	Graphite epoxy	2.874
Structure shell	Aluminum	5.783
Dampers	Silicone	0.230
AFEE Circuit Card Assy's (incl AFEE – TEM cables)		1.660
Fasteners, miscellaneous		0.400
CAL Module Total Mass		**85.99**
Calorimeter Total Mass		**1376**
CAL Module Allocation		**1440**
Mass Margin		**64**

The total amount of passive material (non-CDE) contained in the Calorimeter (13.7%) meets LAT rqmt of < 16% (Level III – 5.5.4)

Power Budget

The Calorimeter Subsystem has a 70% power margin

Component	Quantity	Power (mW)	
		Each	Total
GCFE	48	11.4	547
GCRC	4	64	256
ADC MAX145	48	0.042	2
DAC MAX5121	1	4.5	4.5
References	2	13.5	27
Total Power per AFEE (mW)			**836.5**
CAL Module Total Power (W)			**3.35**
Calorimeter Total Power (W)			**53.5**
Calorimeter Allocation (W)			**91****
Power Margin (W)			**37.5**

***** Modified to 64 Watts, pending CCB action***

Verification & Test

- Engineering model to undergo Qualification testing
  - EM Qual is dry run for Flight Model A Qualification testing
    - Risk mitigation for Flight production schedule
  - Test procedures will be updated prior to FMA testing
  - EM is specially instrumented to assist thermal profiling
- Structural Model (SM) and Structural Flight Model (SFM) testing will qualify change in Composite Structure process
  - Vibration testing at Qualification levels
  - Flight structure with mass simulators for CDEs, electronics
- Qualification model (FMA) and Flight spare (FMB) are first units off flight production line
  - Vibration testing at Qualification levels
  - 12 Thermal-Vacuum Cycles at Qualification levels
  - EMI/EMC testing
- Sixteen Flight models undergo Acceptance testing
  - Vibration testing and 4 Thermal-Vacuum Cycles at Acceptance levels

Verification & Test (cont)

- **Verification Process**
  - In-process inspection/verification essential for minimizing assembly issues and verification anomalies
    - All CDEs undergo functional testing prior to integration
      - Sample CDEs from lots individually Qual tested
    - Each Pre-Electronics Module functionally tested prior to next level of integration
    - Every Analog Front End Electronics assembly fully tested and burned in prior to PEM integration
- **Test configuration includes Engineering model TEM and PS**
  - Separate sets for EM CAL and each Flight Model CAL
    - EM1 TEM & PS for EM
    - EM2 TEM & PS for Flight models
  - EM TEM & PS are supplied fully tested and capable of operation in full test environment

All operations are performed using established procedures and under temperature, humidity, and contamination controlled environment

Verification Matrix

From CAL Module Verification & Environmental Test Plan – LAT-SS-01345

		HARDWARE				MECHANICAL							ELECTRICAL					THERMAL				OTHER					
MODEL	LEVEL	COMPONENT (ITEM)	QUANTITY	TYPE	SUPPLIER	STATIC LOAD	SINE BURST	SINE SWEEP	RANDOM VIB	ACOUSTIC	PRESSURE PROFILE	MASS PROPERTIES	INTERFACE VERIFICATION	EMC/EMI	ESD COMPATABILITY (GRD)	MAGNETICS	FUNCTIONAL	THERMAL VACUUM	THERMAL BALANCE	THERMAL CYCLE	HUMIDITY	RADIATION	BAKEOUT	BEAM TEST-EM SHOWERS	BEAM TEST-HADRONS	BEAM TEST - HEAVY IONS	COMMENTS
	C	VM2 CsI Det Elements (CDE)	12	Q	F	A			A			M	T	A	A	A	T	TQ		TQ		T					
	C	VM2 PreElect Modules (PEM)	1	Q	F	T	TQ	TQ	TQ		TQ	M	T				T	TQ		TQ			T				
	C	VM Electronics Prototype	1	Q	N												T										
	C	EM CsI Det Elements (CDE)		Q	F/N							M	T				T			TQ	M	TQ					TQ applies to sample batches
	C	EM Composite Structure	1	Q	F	TQ						M											A				
	C	EM Front End Elect (AFEE)	4	Q	N	A	A	A	A			M	T	A	A	A	T			TQ	M	A	A				
	S	**EM CAL Module**	1	Q	N		TQ	TQ	TQ		A	M	T	T	T	T	T	TQ			M	A	A	T	T	T	
	S	**SM CAL Module**	1	Q	F	TQ	TQ	TQ	TQ			M											A				Structural Model
	S	**SFM CAL Module**	1	Q	F	TQ	TQ	TQ	TQ			M											A				Structural Flight Model
	C	QM CsI Det Elements (CDE)		Q	F							M	T				T			TQ	M	TQ					TQ applies to sample batches
	C	QM Composite Structure	1	Q	F	TQ						M											A				
	C	QM Front End Elect (AFEE)	4	Q	N	A	A	A	A			M	T	A	A	A	T			TQ	M	A	A				
	S	**QM CAL Module**	1	Q	N		TQ	TQ	TQ		A	M	T	T	T	T	T	TQ			M	A	A				
	C	FM CsI Det Elements (CDE)		F	F							M	T				T			TQ	M	TQ					TQ applies to sample batches
	C	FM Composite Structure		F	F	TA						M											QS				
	C	FM Front End Elect (AFEE)		F	N	QS	QS	QS	QS			M	T	QS	QS	QS	T			TQ	M	QS	QS				
	S	**FM CAL Module**	17	F	N		TA	TA	TA		QS	M	T	QS	QS	QS	T	TA			M	QS	QS				

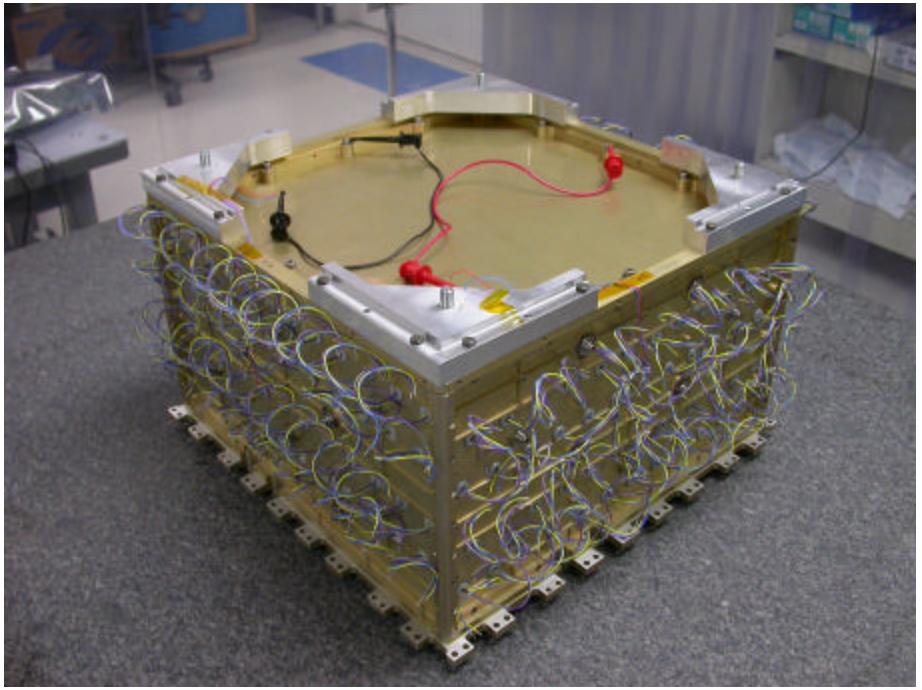
LEVEL OF ASSEMBLY:	SUPPLIER:	UNIT TYPE:	VERIFICATION METHOD:	
S = Subsystem	F = France	PR = ProtoFlight	T = Test	TQ = Test, Qual. Level
C = Component	N = NRL	F = Flight	A = Analysis	QS = Qual by Similarity
		S = Spare	M = Measurement	TA = Test, Acceptance Level
		Q = Qualification Unit	I = Inspection	

Fidelity of EM to FM

- **Designed and fabricated to be as accurate a representation of the flight CAL module as possible**
  - **Principle: "Full flight form, fit and function"**
  - **Flight quality parts where available**
- **Known deviations from flight modules:**
  - **PIN photodiodes**
    - **FM DPD is smaller than EM by 1 mm in 2 dimensions, electrical connections are moved**
    - **FM DPD optical window has changed to ShinEtsu silicone**
    - **Additional tests of CsI-DPD bonding process are needed for new optical window. Initial tests are fully successful.**
  - **14 of 96 EM CDEs were manufactured in France**
  - **ASICs**
    - **FM GCFE will be version 9. EM is version 7**
    - **FM GCRC will be version 5. EM is version 4**
  - **FM composite structure will use an improved (autoclaved) curing process**
  - **FM surface treatment on baseplate tabs may be different**

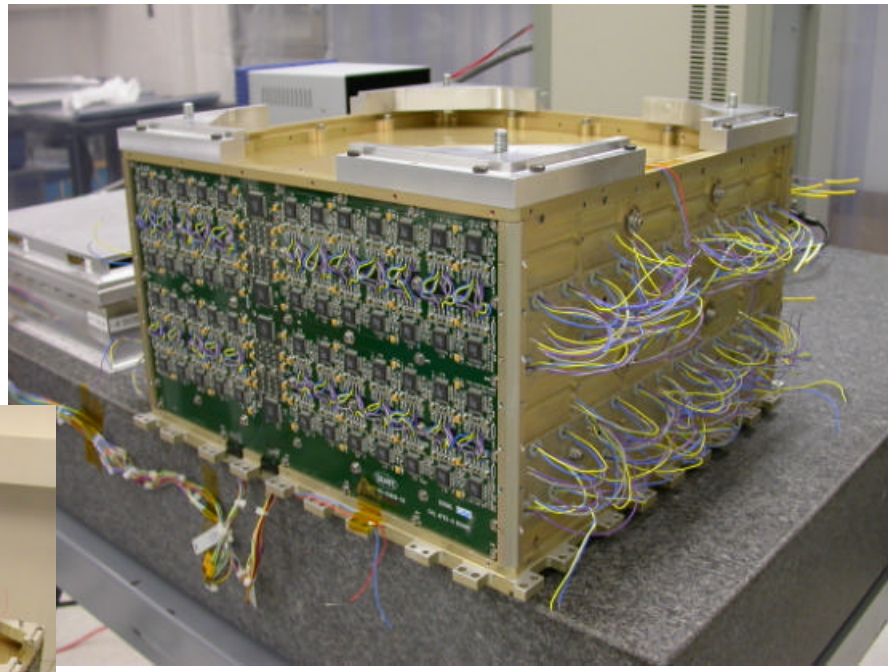
Engineering Model Status

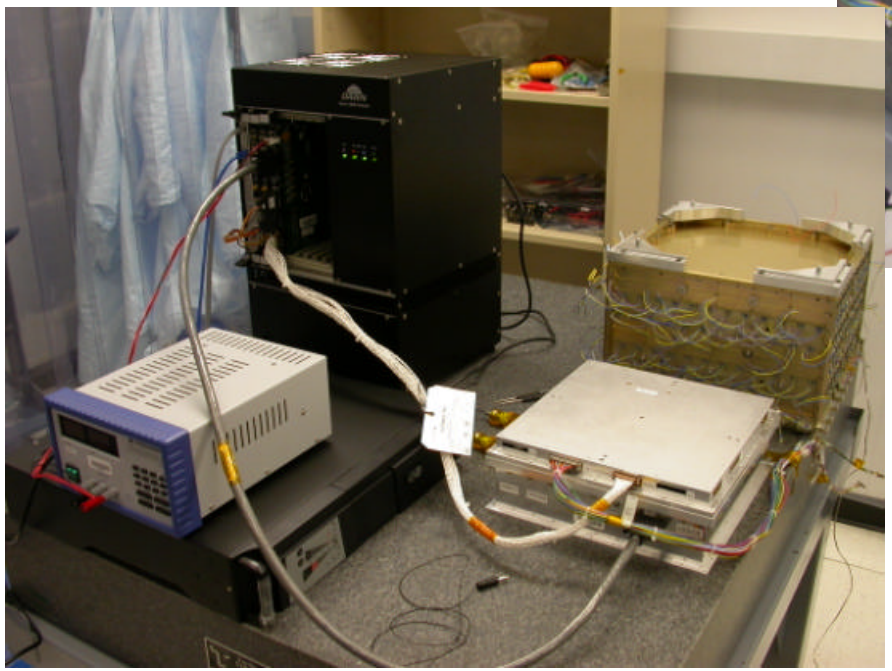
- **Fabricated 124 CDEs, needed 96**
  - 110 CDEs from US, 14 from France
  - All Engineering model CDEs were functionally tested
  - US and France CDEs have identical performance
    - Two CDEs contain DPDs with new optical window for Flight
- **PEM – CDE integration is complete**
  - 96 CDEs installed
    - All 14 from France
    - 82 from US, including 2 with new DPDs
  - Inner closeout plates installed
  - PEM testing completed



Engineering Model Status (cont)

- Assembly of all four EM AFEE boards complete
  - Both AFEE-X boards have been tested, Y boards are underway
  - One AFEE-X board is integrated



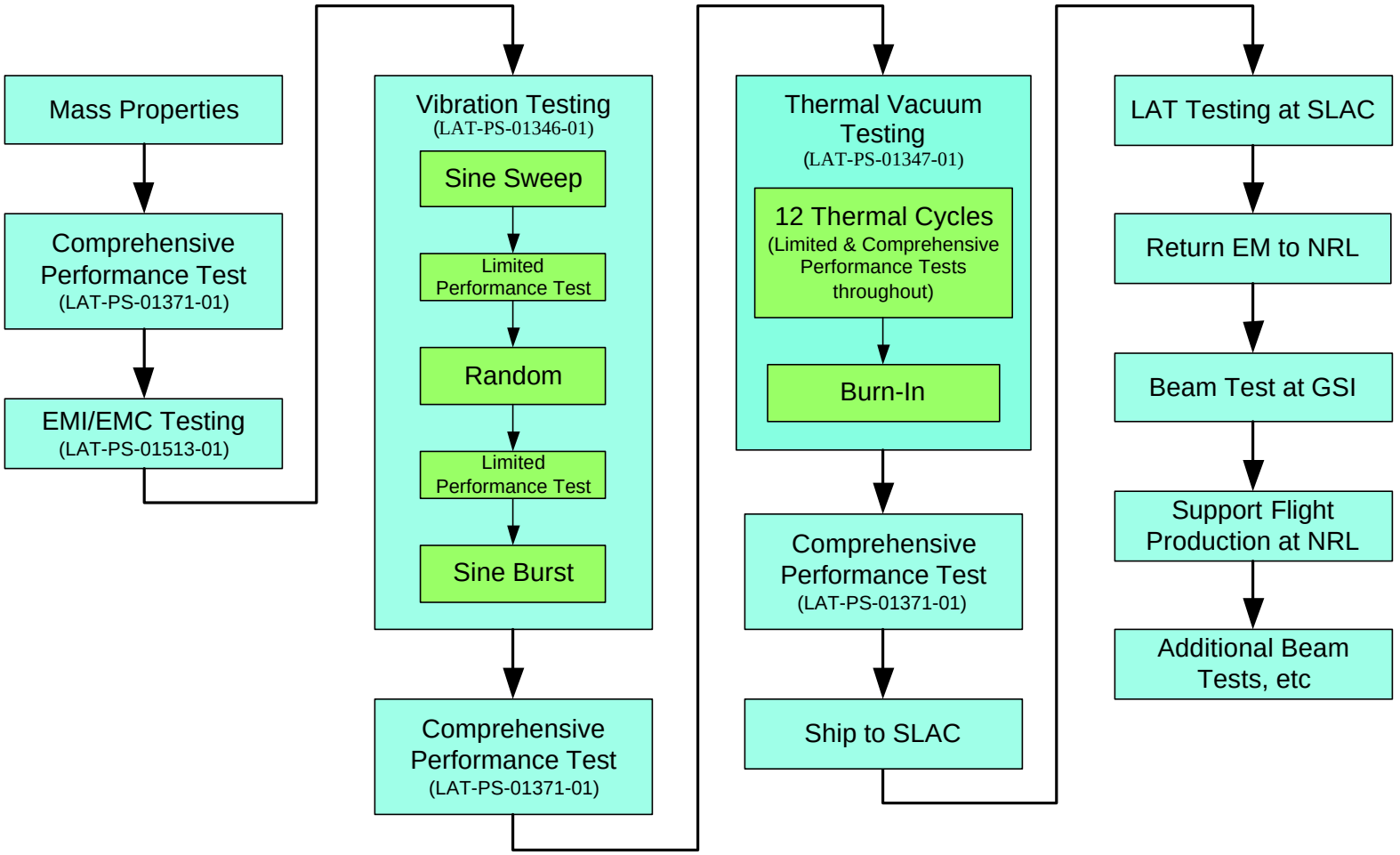


- Preliminary testing of installed AFEE board is in progress
  - Verified Calorimeter Test Stand
  - Verified AFEE board integration
- Remaining AFEE boards are being integrated

Near Term EM Schedule

- PEM assembly completed – Feb 10
- PEM – AFEE Integration is progress
  - First AFEE board integrated – March 10
  - Preliminary testing of installed AFEE board – began March 13
  - Integrate remaining boards – to be completed by March 26
- CAL – TEM Integration – begins March 28
- EM Verification Testing

EM Verification Test Flow



Engineering Model Schedule

Level 3 schedule

Activity Description	Total Float	Orig Dur	Early Start	Early Finish
CAL EM				
4.1.5.9 CALORIMETER MODULE ASSEMBLY, TEST & CAL				
ND: Receive PreEM TEM from Elec to CAL		0		09/04/02A
ND: EM1 EGSE WS-S/W R2		0		12/13/02A
Receipt inspection	19	2	02/21/03	02/24/03
PEM-to-AFEE integration	19	15	02/25/03	03/17/03
TEM Integration	19	5	03/18/03	03/24/03
Comprehensive State Functional test	19	5	03/25/03	03/31/03
Electronic calib	19	5	04/01/03	04/07/03
Muon calibration #2	19	5	04/08/03	04/14/03
EMC/EMI test	19	3	04/15/03	04/17/03
Mass properties #2	19	2	04/18/03	04/21/03
Vibration test	19	10	04/22/03	05/05/03
Thermal vac/ functional test	19	15	05/06/03	05/27/03
EM additional 8 TV Cycles	27	16	05/28/03	06/12/03
Muon calibration #3	18	3	06/13/03	06/17/03
Comprehensive Functional Test #2	18	5	06/18/03	06/24/03
Ready for CAL CDR	202	0		06/24/03
Ship to SLAC	18	4	06/25/03	06/30/03
AV: EM from Calorimeter to I&T	18	0		06/30/03
AV: CAL Released Drawing Pkg to I&T	202	0		07/25/03
ND: EM CAL Returned to NRL (arrives on dock)	123	0		08/26/03
Ship to beam test	81	5	10/27/03*	10/31/03
Hadronic beam test	81	20	11/03/03	12/02/03
EM Support for procedure development	81	44	12/03/03	02/12/04